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POLLUTION OF RIVER WATER IN THE PITTSBURGH DISTRICT[1]

By C. M. Young[2]

The contamination of surface water with waste products of industrial activity is undoubtedly greater in the Pittsburgh industrial district than anywhere else in America. Probably there exists nowhere else in the world a region where so great an amount of waste material finds its way into streams. Some industrial waste is comparatively harmless, but that which appears in the streams of the Pittsburgh district is mostly harmful, mostly acid in character, and to be measured in terms of sulphuric acid.

The condition of acidity of streams has been approached so gradually that it has commonly passed almost unnoticed except by those immediately concerned with the use of water for boiler purposes or the supply of water to towns and cities. At length the change in character of stream waters became so apparent that the United States Engineer Office of the Pittsburgh district decided upon an investigation, which was commenced in 1914. The Engineer Office is the local branch of the Corps of Engineers of the War Department, which has control of all navigable streams. As the Ohio, the Allegheny, and the Monongahela are navigable, the War Department has control of them and of all their tributaries. The Pittsburgh district extends from Steubenville, Ohio, to the headwaters of all tributaries of the Ohio River which enter it above Steubenville, thus covering parts of Ohio, West Virginia, Pennsylvania, and New York. This is the territory covered by the invesgation under discussion and designated as the Pittsburgh District.

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[1] This paper was prepared at the request of the Coal and Coke Committee of the American Institute of Mining and Metallurgical Engineers. It was finally decided, however, that the subject of water pollution was rather more within the field of the American Water Works Association than that of the Institute, and accordingly the Association was given the opportunity of publishing first in the Journal this valuable discussion of an important subject. Discussion of the paper is invited and should be sent to the Editor.

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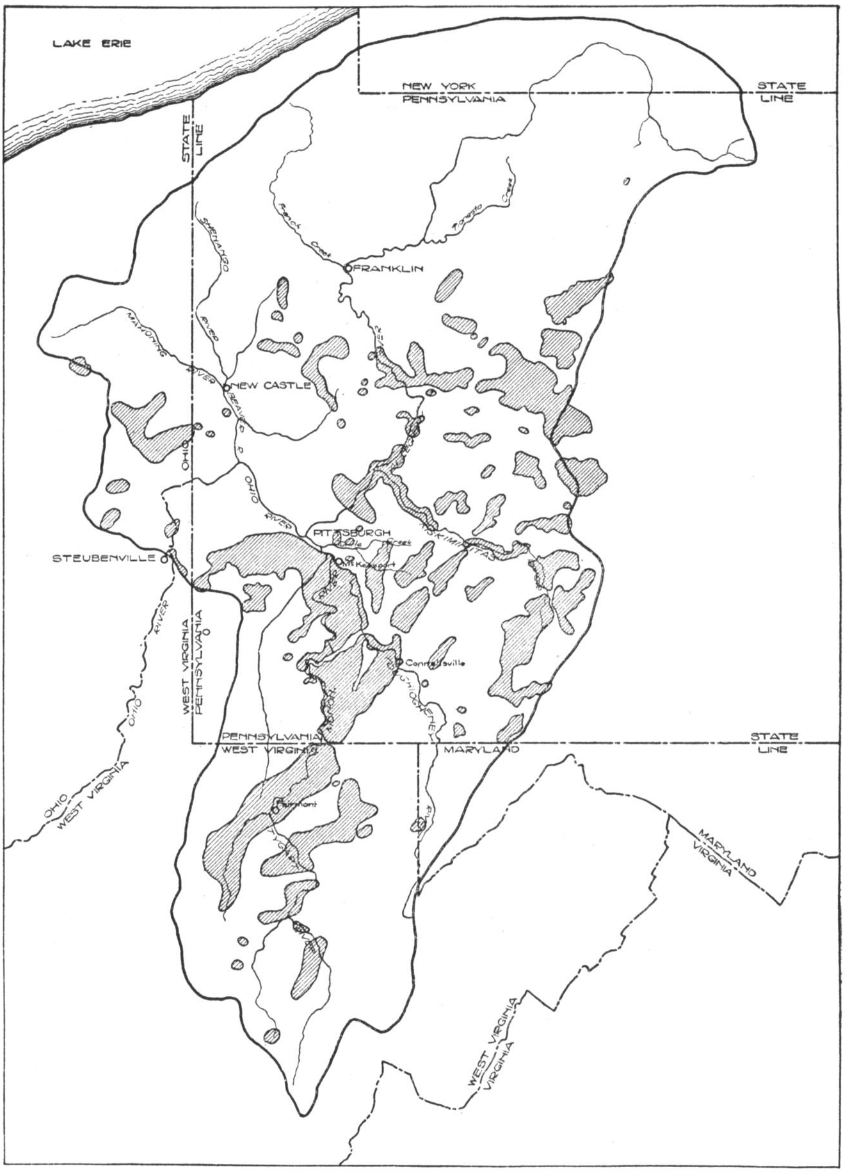

Pittsburgh District of the Engineer Department, United States Army

Approximate boundary shown by heavy line; territory included is the drainage area of the Ohio River above Steubenville. Cross-hatched areas are coal fields now being worked, according to the U. S. Geological Survey. In this district there were, in 1914, at least 1227 going coal mines, and hundreds of abandoned mines, 38 coal washeries, 116 blast furnaces, 63 sheet and tin plate mills, 15 tube mills, 13 wire mills, 49 oil refineries, 8 paper and pulp mills, 18 tanneries, numerous chemical works, numerous rolling mills, several thousand oil wells.

It was thus entirely proper that the investigation should be undertaken by a branch of the federal government, since the damage done in one state is sometimes caused by materials which enter the streams from other states, and since no other agency could well cover so large a territory.

The investigation had been carried on for some months when the author became connected with it, as a specialist, in the fall of 1914. The following discussion of conditions is based upon the material collected in the course of this investigation, a large part of which was collected before the author became associated with the work, largely by T. P. Roberts, Assistant Engineer, and A. F. Hoffman, Superintendent. It is published here with the consent of the District Engineer Officer of the Pittsburgh District, with the understanding that, while the material is derived from the facts collected in the course of this investigation, any opinions expressed are those of the author.

All of the following statements may be considered as made in 1914, but there has been practically no change in conditions since that time except a gradual increase in the extent of pollution.

Character of the pollution. The substances present in the river waters which are direct results of industrial activities are principally sulphuric acid and the sulphates of various metals, hydrochloric acid and chlorides, soluble organic matter and sulphite liquors from paper mills, decaying animal matter and tannates from tanneries, and salt water from oil wells. There is also a very large quantity of sewage from the various towns and villages scattered over the district.

Nature and amount of foreign matter in streams. In quantity of material and damage done, by far the most important constituent of the industrial wastes entering the streams is sulphuric acid, with the various sulphates formed by its combination with metals. This acid comes from various sources, the most important of which are mine water and waste pickle from tin plate, tube and wire mills.

Most of this acid pollution comes from the drainage of coal mines. Pyrite in the coal and the overlying rock is exposed by the processes of mining to the action of air and water. Under these circumstances it is changed by a process which may be represented by the following equation into sulphuric acid and ferrous sulphate:

$$2\ FeS_2 + 7\ O_2 + 2H_2O = 2\ FeSO_4 + 2\ H_2SO_4$$

No claim is made that this reaction exactly expresses the chemical changes taking place, but it is the simplest expression of the union of ferrous sulphide, oxygen, and water, to form the sulphuric acid and ferrous sulphate. We know of the presence of the pyrite, the oxygen, and the water, and of the presence in the effluent water of sulphuric acid and ferrous sulphate. Quite possibly other compounds are formed. Moreover, this reaction supposes the existence of pure pyrite and pure water, while we know as a matter of fact that the pyrite may contain traces of other substances than iron and sulphur, and that the water entering the reaction does carry dissolved substances, so that the reaction which takes place can not well be as simple as that expressed above. However, the most important of the immediate products of the combination are the sulphuric acid and the ferrous sulphate.

The further history of these two substances leads to various modifications. The sulphuric acid may leave the mine and enter a stream in its natural state, and very large quantities of sulphuric acid do so; on the other hand, it may come in contact with iron sulphide, with which it will react, forming hydrogen sulphide and ferrous sulphate, or through contact with calcium carbonate existing in limestone or in shale it may be converted into calcium sulphate, which substance also is present in large quantities in the streams of this region. The ferrous sulphate may come in contact with limestone, with which it will react with the formation of calcium sulphate and ferrous carbonate, the latter of which will immediately decompose, forming ferrous hydrate and giving off carbon dioxide.

The ferrous sulphate, unless previously precipitated, is eventually converted into ferric sulphate, approximately as follows:

$$2\ FeSO_4 + H_2SO_4 + O = Fe_2(SO_4)_3 + H_2O$$

In this case half of the free acid is consumed. Analyses of mine water show that the free acid decreases as the iron is changed to the ferric condition. Possibly also oxidation occurs as follows:

$$6\ FeSO_4 + 3\ H_2O + 3\ O = 2\ Fe_2(SO_4)_3 + 2\ Fe(OH)_3$$

In some cases the concentration of ferric sulphate is sufficient to give the water a yellow or reddish brown color. In its course over the rocks of the district, in which limestones are common, this ferric sulphate is largely decomposed into calcium sulphate and ferric hydrate, the latter being deposited and covering the bottoms of the streams with its characteristic brown coating.

The ultimate course, then, of the pyrite which is found in the coal and the surrounding rocks of this district is conversion into sulphuric acid and ferrous sulphate, the latter changing with oxidation to ferric sulphate, the iron of the ferric sulphate finally being deposited as ferric hydrate and the sulphuric acid going into combination with calcium or magnesium to form calcium sulphate. Probably, however, the changes taking place are less simple than those outlined, and the substance which is deposited is probably in most cases not a simple hydrate but a basic ferric sulphate. It is useless to attempt to give the chemical composition of such a basic sulphate as it may take any of several forms. But the streams of this district are so fully charged in some places with the acid and the iron salts that the decomposition does not take place immediately and the streams themselves sometimes carry appreciable and damaging quantities of free sulphuric acid and of ferric sulphates, as well as large quantities of calcium sulphate.

The following analyses of mine water give an idea of the character and extent of contamination.

	GRAINS PER U. S. GALLON	
	Mine A	Mine B
$NaCl$	1.75	2.59
Na_2SO_4	13.12	10.34
$CaSO_4$	86.30	32.05
$MgSO_4$	56.54	22.09
SiO_2	2.10	2.33
Fe_2O_3 and Al_2O_3		51.54
Fe_3O_3	12.07	
FeO	72.53	16.50
Al_2O_3	6.65	
SO_3	93.23	93.44
H_2SO_4 (free)	26.30	213.50

Both of the mines are situated in the Connellsville district, but the amounts of acid discharged are very different. As is shown by the analyses, the amounts per gallon of sulphuric acid combined in iron and aluminum salts are approximately the same, while the amount of free sulphuric acid in the second is eight times as great as in the first. The maximum discharge from the first mine is 1,500,000 gallons per day and the minimum 750,000 gallons; while the maximum discharge from the second mine is 15,000,000 gallons per day and the minimum 5,000,000. The first mine showed a minimum discharge of one ton of free sulphuric acid per day, and the second a maximum of 180 tons per day, the acid content of the water changing somewhat with the quantity of the latter discharged.

The average discharge of water per ton of coal in the Connellsville district has been variously estimated at from 3.50 to 5.47 tons of water per ton of coal. This gives some idea of the immense amount of acid, free and combined, which is discharged into the streams from the Connellsville district alone. The conditions of mines in other districts are not unlike those of the Connellsville district, as far as acidity of drainage water is concerned, and at the time when this investigation was carried on, there were known to be 1227 operating coal mines in the district. It can hardly be estimated that the average drainage is less than three tons of water per ton of coal, and as about 150,000,000 tons of coal were being produced in the district per annum at that time, the drainage from the mines was approximately 450,000,000 tons of water. While it is impossible to determine the actual acid content of this water, it seems safe to assume that, taking into consideration free and combined acids, the total discharge does not amount to less than 200 grains per gallon, or approximately 7 pounds of sulphuric acid per ton of water, either free or combined in salts. With this rate of discharge, there would be a flow of 1,575,000 tons of sulphuric acid into the streams of the district per year, or approximately 4300 tons per day. There is also a considerable discharge from the large number of abandoned mines of the district, some of them of large size.

A large amount of acid also comes from the waste dumps of coal washeries. At the time of the investigation approximately 6,000,000 tons of bituminous coal were being washed per year, and it was estimated that the refuse from these would contain some 90,000 tons of sulphur per annum. Of course, the oxidation of this material to acid is not immediate, and probably it is less rapid than the accumulation of the material. Also, in many cases these refuse dumps will be burned and the sulphur volatilized, the iron being left behind as oxide. Nevertheless, these refuse piles contribute to the streams of the district very large quantities of sulphuric acid and its salts.

The streams of this district drain the coal fields of northern West Virginia, and all of western Pennsylvania. There is some mining in eastern Ohio in the district under consideration and numerous abandoned mines, but most of the Ohio mines are south of Steubenville and therefore outside the district. These southern Ohio mines contribute largely to the pollution of the lower Ohio. The greatest part of the present development is on the watershed of the Monongahela, but development is increasing on the watershed of the Allegheny.

There is concentrated industrial activity along the streams of the district, quite largely associated with the production of iron and steel. This extends along the Monongahela for some miles above Pittsburgh and up the Mahoning to Warren, Ohio. There are also various other activities scattered through the district. The topography is such that mine water commonly finds its way almost directly to the streams without the opportunity for precipitation or oxidation which would be given by slower percolation through the soil. The topography also restricts the railroads to the stream valleys and this in turn restricts industrial plants largely to these valleys. There is thus concentrated in the valleys which carry the water, already somewhat polluted, an industrial activity which not only adds to this pollution but which is seriously injured by it, inasmuch as most of the industrial plants have to use the stream water for boiler purposes and in some cases for cooling purposes.

An appreciable quantity of acid in the water of some of the streams comes from the pickling liquors used for cleansing iron in the manufacture of sheets, tin plate, tubes, and wire. At the time of the investigation there were in the district at least 63 sheet and tin mills, 15 tube mills and 13 wire mills. When running at full capacity, these would use respectively a total of about 700, 200, and 400 tons of sulphuric acid per day, or approximately 390,000 tons per annum. Most of the sulphuric acid is converted into iron sulphate, and it is sometimes recovered in that form, but it seems to be the common custom to allow it to flow into the streams, though in some cases the waste acids are dumped onto slag heaps, where the acid itself and its iron salt will be converted into the calcium salt.

At least 49 oil refineries were located in the district, which used large quantities of sulphuric acid, though no definite figures could be collected of the amount used. Various other plants, such as paper mills, rolling mills, tanneries, and oil wells discharge waste into the streams, but their total contribution to the pollution, while considerable in itself, is small in comparison with that of the mines and the tin, tube, and sheet mills.

There is no definite figure of the relative amounts of acid and acid salts contributed by the mines and by the mills mentioned, but it is certain that the discharge of acid from the mines is very much greater than that from the mills. On the other hand, most of this mine water has opportunity for neutralization before the more thickly settled part of the district is reached, because the streams are naturally alkaline. Nevertheless, the contamination from mine water is important, because if it were not for this, the streams would reach the concentrated industrial area strongly alkaline, and the amount of acid added to them in their flow through this district would not, under present conditions, be sufficient to make them acid, but reaching the district already partly or wholly neutralized, or even acid, the addition of acid waste by the manufacturing plants makes them acid or adds to the acid already present.

In the course of this investigation numerous samples were taken from the Allegheny, the Monongahela, and the Ohio and the flow of the streams recorded for the time of the sampling. The flow of the stream was estimated in each case from the height of water over the dam and records of this are kept constantly in the Engineer Office. Most analyses were for free acid and decomposable salts only. Various other analyses were collected, some of them made by the Public Health Department, and large numbers were compared.

In the case of those analyses made for the investigation under discussion, free acid was determined by titration with methyl orange as an indicator. Decomposable salts and free acid together were determined with the use of phenolphthalein, after boiling to remove carbon dioxide, and the result calculated as sulphuric acid. It is possible for water to be neutral to methyl orange while acid to phenolphthalein, in which case all the acidity would be present as decomposable salts of iron and aluminum. There are cases also in which methyl orange shows alkalinity, while phenolphthalein shows acidity, in which case the acidity to phenolphthalein plus the alkalinity to methyl orange represents the decomposable salts. In case the methyl orange shows acidity and phenolphthalein a greater acidity, the free acid is shown by the methyl orange and the decomposable salts by the difference between that and the total acidity shown by phenolphthalein. The following extract from the analyses and records of stream flow indicates the conditions encountered.

Sample extract from analyses and records of stream flow

NUMBER	DATE, 1914	ORIGIN OF SAMPLE, LOCK NUMBER AND RIVER	ACIDITY −, ALKALINITY +, PARTS PER MILLION		DISCHARGE PER SECOND	TONS PER 24 HOURS	
			Methyl orange; free acid	Phenolphthalein; free acid and decomposable salts		Free acid	Decomposable salts
					cu. ft.		
1	May 21	No. 2 Mon. R.	0.0	−40.0	3,519	0	380.0
2	May 21	No. 2 Alleg. R.	+10.0	−3.0	22,878	0	803.0
3	May 21	No. 3 Ohio R.	+9.0	−3.0	26,397	0	855.0
4	June 6	No. 2 Mon. R.	−34.0	−78.0	4,000	367.2	475.2
5	June 6	No. 2 Alleg. R.	+19.2	+6.0	13,918	0	498.3
6	June 6	No. 3 Ohio R.	+16.4	+4.0	17,981	0	602.0
7	June 26	No. 2 Mon. R.	−80.0	−279.0	2,250	486.0	1209.0
8	June 26	No. 2 Alleg. R.	+5.0	−18.0	11,300		701.7
9	June 26	No. 3 Ohio R.	+18.0	0.0	13,650		663.4
10	August 26	No. 3 Mon.	+9.75	−11.7	600		34.7

Group 1, 2, 3 shows that a total of 1183 tons of acid and decomposable salts calculated as acid passed Locks No. 2 on the Allegheny and Monongahela, also some 200 tons was probably added from industrial plants below these locks; yet only 855 tons appeared at Lock 3 on the Ohio. Something over 500 tons had disappeared, neutralized by sewage and by treatment for industrial uses.

Group 4, 5, 6 shows a large amount of free acid in the Monongahela, and the disappearance of a considerable amount of the acidity above Lock 3 on the Ohio.

No. 7 shows a high acidity, probably due to the flushing of pools by a slight rise. A few days before, the discharge had been only 750 second-feet.

The treatment of the water for boiler use commonly renders the water alkaline, and the discharge of this water into the streams after its condensation has a considerable effect in decreasing the total acidity. In this way the intense industrial activity is of benefit to the streams, but the cost of this treatment of feed water is a severe tax on the industries.

Analysis 10 seems to illustrate this, as it shows a condition of very low acidity at a time of low discharge. As the flow from mines is much less variable than the stream flow and the amount of acid discharged fairly uniform, concentration of acid at periods of low water would be expected. The probable explanation of low acidity in this case is neutralization for boiler use and by influx of alkaline sewage. The stream showed 118 tons of acid combined in stable salts, mostly sodium sulphate, which indicates feed water treatment.

It is estimated that about one fifth of the acid occurring in the Pittsburg district is free sulphuric acid. About one half of the acid is combined with calcium and magnesium or with alkalies, into salts which do not decompose under boiler conditions, and the remainder is present as sulphates of iron and aluminum, which do decompose in the boilers.

It is probably safe to estimate that four-fifths of the sulphuric acid and sulphates entering the stream are neutralized by the natural alkalinity of the water before reaching Pittsburgh. At the present time the Allegheny River rarely shows free acid, the Monongahela shows free acid most of the time, and the Ohio River only during periods of low water. All three of these rivers show considerable quantities of acid in the form of decomposable salts of iron and aluminum.

The effect of development of the coal industry is plainly shown by the conditions of the two streams, the Monongahela with its largely developed coal industry commonly showing free acid, while the Allegheny rarely shows it. However, the mining industry is being developed in the drainage area of the Allegheny, and the periods of acidity of that stream are becoming more frequent and prolonged.

Sewage discharged into the streams. To a considerable extent the acid which reaches the more thickly settled parts of the district seems to be neutralized by sewage, and considerable amounts disappear in the passage through the Pittsburgh district.

The average daily sewage discharge from a district containing 590,000 persons was found by the Department of Health of Pittsburgh to be 164 gallons per capita. On this basis the sewage from the entire district was estimated at 900 second-feet. The average alkalinity of the sewage of Pittsburgh was found to be 94 parts per million, and assuming this alkalinity for the entire district, the total discharge provides sufficient alkalinity to neutralize 228 tons of free sulphuric acid or its decomposable salts each 24 hours. There are times when even more than this is neutralized.

The presence of the mine and mill waste in the rivers of the district has been in one way a very fortunate thing for the city of Pittsburgh, as this acid has reacted with the sewage in such a way as to precipitate it and prevent the putrefaction which would otherwise have taken place in the rivers. This seems to be the one advantage of the presence of acid in the streams, all its other effects being deleterious.

Damage from acid pollution. The presence in the water of the acid and its combinations leads to many serious inconveniences and to great expense. No attempt is made here to mention all the harmful effects of pollution, only those being considered which are of greatest importance.

Probably the most conspicuous effect of the acid is found in the use of water in boilers. All forms in which the SO_4 reaches the boilers seem to be harmful. The formation of scale by calcium and magnesium salts is well known. The effect of the free sulphuric acid and of that combined in iron and aluminum salts is more harmful. The free sulphuric acid readily combines with iron in the boiler to form ferrous sulphate. This is oxidized, if there is oxygen present in the water, to ferric sulphate, which decomposes to form ferric hydrate and sulphuric acid, the acid again attacking the iron and this process being continued as long as the oxygen supply holds out. The ferric and aluminum salts which are present in the water are decomposed under boiler conditions, acting as does the iron sulphate formed in the boiler from the free sulphuric acid, all of the SO_4 eventually combining with the iron in the boiler to form a sulphate, which is decomposed into hydrate if oxygen is present.

An illustration of the damage caused by the acid may be taken from the experience of the railroads. One of these, whose tracks are along the Mahoning and Youghiogheny Rivers, was maintaining fifteen plants for the treatment of locomotive water, these plants costing $250,000, and was spending $20,000 per year for chemicals. The total cost of operation, including chemicals, overhead expense, labor, 6 per cent interest on the investment, depreciation and repairs, brought the cost of treating water up to $60,000 per annum for the 258 locomotives of that company operating in the district.

Notwithstanding this treatment, great damage was caused. With use of good water, locomotive boiler tubes should last from twelve to fifteen years, but under the existing conditions they were lasting from twelve to fifteen months, at which time they had to be safe ended, and in five or six years had to be replaced. The annual cost of tube trouble per locomotive was given as $225, and $155 was considered the annual loss chargeable to impurities in the water.

It was also found that fire boxes had to be removed twice as frequently as with good water. This requires that the locomotive be out of commission for three weeks, and costs $1500. The railroad mentioned was spending about $300 per annum per locomotive for this purpose, about $150 of which could fairly be charged to the condition of the water.

Locomotive boilers under normal conditions should do service for about twenty-five years, but in this district they are rendered unserviceable in fifteen years or less. Assuming the cost as $3500, the annual deterioration due to bad water amounts to $93.33.

Because of the heavy deposits of chemicals, scale, mud, etc., it is necessary to wash boilers frequently, this operation costing about $2.50. As each boiler is washed on the average of 24 times per year, the annual cost amounts to $60 per locomotive. This is small, but it is twice as great as is necessary with ordinary water, and the condition of the water is therefore chargeable with an expense of about $30 per locomotive per annum for this purpose.

There is a greater loss, however, than any of these which have been mentioned, namely the waste of fuel caused by scale, and the necessity of blowing off large quantities of steam and hot water. The mechanical engineer of the railroad mentioned estimated that the fuel loss, in excess of the normal, was about $1.50 per day, as a result of scale. In order to make this loss as small as possible and to reduce risk to the boiler, the boilers are blown off frequently. During dry weather it is not unusual to blow off a boiler three times in a trip of 100 miles, while during other months of the year it is done about once in 100 miles. The resulting loss of fuel and water amounts to roughly $1.60 per day. There are also various other losses which can not readily be estimated, one of the important ones being the failure of locomotives on the road because of boiler leaks, which results in delay of traffic and loss of time on the part of train crews. A summary of the above losses for the one railroad amounts to $1,618 per locomotive per year.

Another railroad in this district, which was then using 250 locomotives, estimated the cost of water treatment also as $60,000 per year. The two railroads together suffer a known loss of about $800,000 per year, but it will be noticed that this is not the total loss, because the many delays incident to trouble caused by bad water could not be estimated and are not included.

The two railroads mentioned are the ones that suffer the greatest damage. There are others in the district, and none is free from the effects of the bad water, though the Pennsylvania railroad has largely overcome this trouble by supplying water from the mountains to the east.

There are also several hundred locomotives of various sizes at the industrial plants, the United States Steel Corporation alone having nearly as many standard gauge locomotives as the second railroad mentioned, as well as a large number of small, narrow-gauge locomotives.

The damage is not confined to railroads, as every producer of steam suffers from it. The conditions are such that it has become necessary to treat all boiler feed water drawn from the rivers of the district. While no complete catalog of the power plants of the district has been made, it has been estimated that some 4,500,000 horse power is developed by steam within a radius of 60 miles of Pittsburgh. All the large manufacturing establishments maintain water-softening plants to neutralize the feed water, and in some of the steel mills there are additional plants for neutralizing the cooling water, in the latter case no attempt being made to remove the scale-forming constituents.

The capital invested in water softening plants in the Pittsburgh district is several million dollars, and the annual cost of treatment, while not known accurately, is certainly very large.

One fact which leads to difficulty in treating water in this district is that the character of the water is not constant but is very variable. As an illustration of this, it may be stated that on some days and under certain conditions of the Youghiogheny River, the chemists at the McKeesport water works test the water every hour, in order that the treatment may be suited to the condition of the entering water.

The Youghiogheny suffers more from contamination with mine water than any other of the larger tributaries of either the Monongahela or Allegheny. At times of low water practically the whole volume of flow of this stream is made up of mine water, and under such conditions it is so badly contaminated that it would not be used either for boiler purposes or domestic use, if other supplies were available. As an illustration, on October 14, 1914, the raw river water at the McKeesport water works showed a hardness of 704 parts per million and contained over 16 grains per gallon of sulphuric acid and nearly 12 grains more sulphuric acid in the form of aluminum and iron salts, the latter of which decompose under boiler conditions. This means that the river contains a total acidity of over 28 grains per gallon and over 41 grains per gallon of incrustants. A 100 horse power boiler, using such water without treatment, would take in from 32 to 40 pounds of sulphuric acid each 24 hours.

The ordinary treatment for boiler water is with lime and soda ash, but with water such as that of the Youghiogheny the amount of sodium sulphate formed is so great that foaming soon occurs and it is necessary to blow off the boiler frequently.

Water works. It has already been stated that all water used for industrial purposes along these streams has to be treated. The same statement is true of water used for domestic purposes. Generally speaking, the acidity of the streams reduces the bacterial growth, but it has not been found safe to assume that because a stream is acid it contains no harmful bacteria. These treatment plants are operated at considerable cost.

The treatment of the water of the Youghiogheny for the city of McKeesport has already been referred to. The supply for the city has been taken from the Youghiogheny since 1881. When the original plant was constructed the water supply was very satisfactory, but since then developments on the watershed have been such that the water has become almost intolerable. The fact that the river water is subject to sudden and important changes required the erection of a complicated plant. This plant was put in operation in October, 1908. During the preceding summer the corrosive action of the water on the pumps, the pipe system and the plumbing fixtures was very serious, and because of leakage it became almost impossible to supply water for the city. The results of operating the plant were very satisfactory, and during the first three months of operation the daily consumption was reduced from about 7,000,000 gallons to less than 4,000,000 gallons, largely through saving of leakage. The cost of chemicals was high, but considered insignificant in comparison with the saving in plumbing, soap, etc. The rapid variations in the character of the water of the Youghiogheny are shown by the following table, giving the analyses of water made for the water works plant in one day. Probably this rapid change was due to waste liquor from an industrial plant not far above the water works.

TIME	TOTAL HARDNESS	ACIDITY, PHENOLPHTHALEIN	ACIDITY, METHYL ORANGE
	p.p.m.	*p.p.m.*	*p.p.m.*
8.00 a.m.	118	90	45
11.00 a.m.	224	150	70
12.00 a.m.	430	300	160
1.00 p.m.	508	340	210
2.00 p.m.	440	230	140
3.00 p.m.	348	160	90
4.00 p.m.	300	110	40
6.00 p.m.	173	80	35
7.00 p.m.	152	70	30
11.00 p.m.	116	65	40

It is the understanding of the author that the city now obtains water from the Monongahela, and the fact that the use of Youghiogheny water had to be abandoned is confirmation of the seriousness of the condition.

Perhaps the situation of the city of Pittsburgh is even more serious. Some years ago an extensive filtration plant was built at Aspinwall on the Allegheny River a few miles above the city. This is a sand filtration plant, depending for its action upon the stoppage by sand of solid matter in the water, and this depends upon the collection of colloidal material on the sand beds. This method of filtration is efficient only with alkaline or neutral water and fails in case of acidity. Unfortunately periods of acidity will become more frequent as the mining industry develops in the valley of the Allegheny and apparently it will be only a few years until it will be necessary to largely add to this plant if the water is to be treated in such a way as to make it safe for domestic use.

Miscellaneous losses. There are various other losses chargeable more or less directly to the pollution with acid which need not be taken up in detail but can be suggested. Among these is that of house plumbing. This matter was investigated and the lowest estimate which could be placed upon the damage due to acidity, founded upon the opinions of plumbers and dealers in plumbers supplies, was $10 per annum for each house. In 1910 the district had a population of 3,167,000, which would require in the neighborhood of 500,000 houses. Assuming that only 300,000 houses should be estimated as having plumbing that would be affected, the damage to these would amount to $3,000,000 per year.

There are also many office buildings and manufacturing plants at which the plumbing was damaged. One rolling mill, taking its water from the Monongahela, was obliged to renew its service pipes on an average of once every three weeks during the summer of 1914.

Considerable, though inestimable, damage is done to the clothing of inhabitants of the district, especially to such clothing as is sent to laundries. The hardness of the water increases the consumption of soap, and when attempts are made to overcome this hardness by addition of chemicals, the clothing is very greatly damaged. The laundries are also inclined to use bleaching powder in excess and clothing is very greatly damaged thereby.

The effect of this contamination of the streams upon organic life is very marked. Fish can not live in water containing free acid or any appreciable quantity of ferric sulphate; therefore the Monongahela has no fish life, the Allegheny has very little, and there are no game fish in the Ohio from Pittsburgh to Parkersburg, 183 miles below Pittsburgh, where the Little Kanawha enters. At this point a few game fish are found, but there is no good fishing in the stream until Point Pleasant, 263 miles below Pittsburgh, is reached. The Shenango has fish above New Castle, and some are found below the town. The Youghiogheny is entirely without fish, except perhaps in the upper portions above the coal fields.

As illustrative of the seriousness of the water situation from the point of view of the steel industry, the following notes on the water treatment at one plant may be given. This is one of the largest steel plants in the world, having eleven blast furnaces, with a daily capacity of about 500 tons each. When operating at full capacity this plant pumps from the river from 50,000,000 to 60,000,000 gallons per day. During ordinary conditions of the river only the water intended for boiler use is treated; during periods of high acidity the entire supply is treated with lime, enough being used to neutralize the high acid without any attempt at complete neutralization. When the plant is running at capacity, about 3,000,000 gallons of water are used per day in boilers, and about 40,000 horse power developed. The treatment of boiler water was commenced about 1904. During ten months in 1914 the water treated amounted to 768,838,000 gallons, the soda ash used was 1,206,655 pounds, or 1.555 pounds per 1000 gallons; and the lime 290,175 pounds, or 0.377 pound per 1000 gallons.

In view of the very serious loss and inconvenience resulting from the extensive pollution of streams in the Pittsburgh district it is regrettable that no simple remedy presents itself. While it would be possible to require that such harmful substances as have been mentioned be kept from the streams, such a course would apparently impose a considerable hardship upon the industries concerned, especially upon coal production. The water from the mines can not be kept out of the streams, and little attempt has been made to purify it. A beginning[3] has, however, been made in this direction and the H. C. Frick Coke Company, is operating a plant for the recovery of by-products from mine water.

In Germany a comparable condition of the Emscher, on which Essen is situated, has been met by the organization of a federation for the construction and maintenance of the necessary means for keeping suspended matter out of the streams.[4] Apparently nothing has been done to prevent substances in solution from entering the streams; possibly the flow of the Emscher is so small in comparison with that of the Rhine which it enters, that its purification was not considered worth while, and possibly it was not considered practicable.

It is the belief of the author that farther research is desirable with the purpose of extending the extraction of valuable substances from mine water. If this can be practicably done the contamination of streams with acid will be reduced, possibly to such an extent that the natural alkalinity of the water will assert itself.

The neutralization of the wastes from manufacturing plants is a much less difficult matter and should not be so expensive as to seriously burden the industries concerned.

Summary. Acid pollution of streams of the Pittsburgh district is due principally to water from coal mines and to manufacturing waste.

There is extensive discharge of sewage, the alkalinity of which partly neutralizes the acidity of the streams.

Fish life is absent from the streams, or is rapidly disappearing.

All water used for boiler purposes must be treated.

Water for municipal supply must be treated.

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[3] C. M. Young, Valuable by-products of coal mining, *The Coal Industry*, Vol. 1. S. D. Tracy, Mine water neutralizing plant at Calumet Mine, *Am. Inst. M. & M. E.*, Lake Superior meeting, 1920.

[4] Charles Saville, The Emscher Federation and the statute under which it operates, *Eng. Rec.*, vol. 66, p. 518 (1912).